

TITLE

Apparatus for Generating Quadrature Phase Signals and
Data Recovery Circuit Using the Same

5 **CROSS-REFERENCE TO RELATED APPLICATIONS**

This application is based upon and claims the benefit of U.S. provisional application No. 60/417,180 filed October 10, 2002, the contents of which are incorporated herein by reference.

10

BACKGROUND OF THE INVENTION

Field of the Invention

This invention relates to a data recovery circuit, and more particularly to a controllable quadrature phase 15 generator in a half-rate data recovery circuit for generating two clock signals that are 90 degrees out of phase with each other.

Description of the Related Art

In digital data processing, all digital data is clocked 20 by an associated clock signal, the period of which is equal to that of the digital data, so that a digital circuit is allowed to process digital data and to function properly. When digital data is transmitted serially, the associated clock signal is not transmitted along with the digital data 25 for the consideration of transmission efficiency. Therefore, the receiving end must be able to extract clock signal from the incoming data so that the received data can be correctly recovered. Phase locked loop (PLL) circuits are generally used in circuits for data recovery. Figure 30 1 shows a schematic block diagram of a conventional data recovery circuit. As shown, a data recovery circuit 10 mainly comprises a clock source 12, a phase detector 14 and

a loop filter 16. The clock source 12 is for example a voltage-controlled oscillator for generating a reference clock signal CLK having the same frequency as the incoming data signal. The phase detector 14 compares the phase of
5 the incoming data signal to the phase of the reference clock signal CLK, determining whether or not these two signals are synchronous with each other. If the incoming data signal leads or lags the reference clock signal CLK, then the phase detector 14 generates a phase error signal which
10 is a function of the phase difference between these two signals. The phase error signal is then applied to the loop filter 16 so as to eliminate the undesired high frequency noise and to output a control signal for feedback to the clock source 12. The clock source 12 is controlled based
15 on the control signal to adjust the phase of the reference clock signal CLK. In this way, the reference clock signal CLK can be synchronized with the incoming data signal and thus may be used for retiming the incoming data signal to thereby produce the correctly recovered data.

20 Recently, the demand for higher transmission speed has been rapidly increasing. However, the maximum data rate allowed by the phase detector in the above full-rate data recovery circuit is approaching the limit. Therefore, such circuit can hardly satisfy the speed demand in high speed
25 serial communication. A half-rate data recovery circuit has been developed to solve this issue. This half-rate data recovery circuit, which operates at a frequency equal to half the rate of the incoming data stream, approximately doubles the maximum data rate allowed to be processed by
30 the circuit at the receiving end.

SUMMARY OF THE INVENTION

Therefore, an object of the present invention is to provide an apparatus for generating two quadrature clock signals, i.e., two clock signals being 90 degrees out of phase with each other, by using a plurality of reference clock signals. The phase of the generated clock signals can be digitally controlled and adjustable through the whole cycle.

Another object of the present invention is to provide a half-rate data recovery circuit using the above apparatus for generating two quadrature clock signals being 90 degrees out of phase with each other and having a frequency equal to half the incoming data rate.

To achieve the above objects, according to one aspect of the present invention, an apparatus for generating quadrature phase signals comprises a base selector, a first phase interpolator and a second phase interpolator. The base selector generates a first, a second, a third and a fourth base clock signals in accordance with a region control signal by using a plurality of reference clock signals of the same frequency and different phases. The first and the second base clock signals are used as boundaries for defining a phase region for a first clock signal while the third and the fourth base clock signals are used as boundaries for defining a phase region for a second clock signal. The phase difference between the first and the second base clock signals is substantially equal to the phase difference between the third and the fourth base clock signals, and the phase difference between the first and the third base clock signals and the phase difference between the second and the fourth base clock signals are both substantially 90 degrees. The first phase

interpolator operates in accordance with a position control signal to generate a first clock signal, the phase of which is a weighted average of the phases of the first and the second base clock signals. Similarly, the second phase
5 interpolator operates in accordance with the same position control signal to generate a second clock signal, the phase of which is a weighted average of the third and the fourth base clock signals. The first and the second clock signals both have the same frequency and are substantially 90
10 degrees out of phase with each other.

According to another aspect of the present invention, a data recovery circuit is designed to incorporate the above apparatus for generating two quadrature clock signals including a first and a second clock signals having a
15 frequency equal to half the frequency of an incoming data signal received by the data recovery circuit. The clock signals are fed into a phase detector for phase comparison with the incoming data, which in turn generates a phase error signal. A digital loop filter operates on the basis of the
20 phase error signal to digitally control the apparatus for generating two quadrature clock signals, adjusting the phases of the generated clock signals so that the second clock signal is synchronous with the incoming data signal and the first clock signal is always maintained 90 degrees
25 out of phase with the second clock signal.

BRIEF DESCRIPTION OF THE DRAWINGS

Objects and advantages of the present invention will be fully understood from the detailed description to follow
30 taken in conjunction with the embodiments as illustrated in the accompanying drawings, wherein:

Figure 1 depicts a schematic block diagram of a

conventional data recovery circuit;

Figure 2 depicts a schematic block diagram of a half-rate data recovery circuit according to the present invention;

5 Figure 3 depicts a timing diagram showing the incoming data signal received by the data recovery circuit and the first and the second clock signals;

Figure 4 depicts a schematic block diagram of a preferred embodiment of the quadrature phase generator according to the present invention;

10 Figures 5(a) and 5(b) respectively show a phase diagram and a phase region table for the quadrature phase generator;

Figure 6 depicts a circuit for implementing the base selector in the quadrature phase generator;

15 Figure 7 is a table showing the relation among the control bits, the mediate clock signals, and the base clock signals;

Figure 8 illustrates the relation between the weight represented by the position control signal and the clock signal generated by the weighted average process;

20 Figure 9 depicts a phase rotation state machine for the quadrature clock signals; and

Figure 10 is a table illustrating the relation between the control signal and the phase rotation of the quadrature clock signals.

25

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Please refer to Figure 2, which shows the schematic block diagram of a half-rate data recovery circuit according to the present invention. As shown, the data recovery circuit 30 mainly comprises a multiphase source 22, a quadrature phase generator 23, a phase detector 24 and a digital loop filter 26. The multiphase source 22 generates a plurality

of reference clock signals of the same frequency and different phases from an external reference clock. In the preferred embodiment, the multiphase source 22 generates four reference clock signals with phases separated by 45
5 degrees, i.e., 0-degree, 45-degree, 90-degree and 135-degree, respectively. The quadrature phase generator 23 receives the four reference clock signals from the multiphase source 22 and generates therefrom a first clock signal CKI (in-phase) and a second clock signal CKQ
10 (quadrature) for outputting to the phase detector 24. Please refer now to the timing diagram in Figure 3. The first and the second clock signals CKI and CKQ are of the same frequency, which is equal to half the frequency of an incoming data signal received by the data recovery circuit
15 20, and are substantially 90 degrees out of phase with each other. The phase detector 24 compares the incoming data signal and the second clock signal CKQ to determine whether or not a phase difference exists therebetween, that is, to determine whether or not the rising edge/falling edge of
20 the second clock signal CKQ is aligned with the transition portion between two adjacent data bits. In Figure 3, a rising edge of the clock signal 32 is aligned with the transition portion 33 between two data bits D0 and D1, a rising edge of the clock signal 32a leads the transition portion
25 33 between two data bits D0 and D1, and a rising edge of the clock signal 32b lags the transition portion 33 between two data bits D0 and D1. If there is no phase difference between the incoming data signal and the second clock signal CKQ, i.e., the rising edge/falling edge of the
30 second clock signal CKQ is aligned with the transition portion between two adjacent data bits, then each rising edge/falling edge of the first clock signal CKI can be

maintain in the central portion 34 of each incoming data bit since the first clock signal CKI is offset from the second clock signal CKQ by 90 degrees. In this way, the most correct result can be obtained in data recovery when
5 the first clock signal CKI is employed for sampling the incoming data signal. If there is a phase difference between the incoming data signal and the second clock signal CKQ, for example, in the cases of the clock signals 32a and 32b, the phase detector 24 generates a phase error signal
10 based on the lead/lag conditions. The digital loop filter 26 operates to filter out undesired high frequency noise, as well as to generate a digital control signal on the basis of the phase error signal generated by the phase detector 24. The digital control signal is fed back to the
15 quadrature phase generator 23 to adjust the phases of the first and the second clock signals CKI and CKQ, so that the phase difference between the incoming data signal and the second clock signal CKQ can be minimized. In the preferred embodiment, the digital control signal comprises a region
20 control signal and a position control signal, which will be better described below.

A preferred embodiment of the quadrature phase generator 23 is shown in Figure 4. The quadrature phase generator 23 comprises a base selector 28, a first phase interpolator
25 29a and a second phase interpolator 29b.

The base selector 28 is provided with a control input terminal for receiving the region control signal from the digital loop filter 26, and four reference clock input terminals for receiving the four reference clock signals from the multiphase source 22. These four reference clock signals, i.e., the 0-degree, 45-degree, 90-degree and
30 135-degree signals, and their inverted signals, i.e., the

180-degree, 225-degree, 270-degree and 315-degree signals, together form eight different phases being evenly spaced apart from one another by 45 degrees to divide the phase plane into eight regions. The base selector 28 selects a
5 first and a second base clock signals B1 and B2 from the four reference clock signals (the 0-degree, 45-degree, 90-degree and 135-degree signals) and their inverted signals (the 180-degree, 225-degree, 270-degree and 315-degree signals) in accordance with the region control
10 signal. The first and the second base clock signals B1 and B2, which are for example separated by 45 degrees, serve as a pair of boundaries for defining the phase region of the first clock signal CKI. The base selector 28 also selects a third and a fourth base clock signals B3 and B4, which are also for example separated by 45 degrees, as a pair of boundaries for defining the phase region of the second clock signal CKQ. Since the first and the second clock signals CKI and CKQ must be 90 degrees out of phase with each other, the first and the third base clock signals
15 B1 and B3 are selected to have phases separated by 90 degrees and the second and the fourth base clock signal B2 and B4 are also selected to have phases separated by 90 degrees. Figures 5(a) and 5(b) respectively show a phase diagram and a phase region table for explaining phase region selection
20 of the first and the second clock signals CKI and CKQ. For instance, as shown in Figure 5(a), when the phase of the first clock signal CKI falls in the region B bounded by two base clock signals having phases of 45-degree and 90-degree respectively, the phase of the second clock signal CKQ falls
25 in the region H bounded by two base clock signals having phases of 0-degree and 315-degree respectively. The discussion here assumes that the first clock signal CKI
30

leads the second clock signal CKQ. However, in practice the first clock signal CKI can also be set to lag the second clock signal CKQ.

Figure 6 illustrates a circuit for implementing the base selector 28. As shown, the base selector 28 includes a buffer/inverter unit 281 and a bypass/cross unit 282 and is controlled by a region control signal having six control bits CA~CF. The buffer/inverter unit 281 consists of, for example, four exclusive-or (XOR) gates 281a~281d. Each of the XOR gates 281a~281d has two input terminals for receiving one of the reference clock signals and one of the control bits CA~CD, respectively, and has an output terminal for outputting one of four mediate clock signals M1~M4. When an XOR gate receives a control bit "0" at one input terminal, the output mediate clock signal will be the same as the reference clock signal at the other input terminal. In this way, the XOR gate acts like a buffer. When an XOR gate receives a control bit "1" at one input terminal, the output mediate clock signal will be the inverted signal of the reference clock signal at the other input terminal. In this way, the XOR gate acts like an inverter. Thereby, the buffer/inverter unit 281 is able to selectively output four mediate clock signals, the phases of which are 0-degree/180-degree, 45-degree /225-degree, 90-degree/270-degree and 135-degree /315-degree, respectively. The bypass/cross unit 282 consists of a first bypass/cross multiplexer 282a and a second bypass/cross multiplexer 282b, each of which is provided with two input terminals and two output terminals and is respectively controlled by a control bit CE or CF. Each of the first and the second bypass/cross multiplexers 282a and 282b operates to direct-connect signals at its two

input terminals to its two output terminals upon receiving a control bit "0" and to cross-connect signals at its two input terminals to its two output terminals upon receiving a control bit "1". In this embodiment, the first 5 bypass/cross multiplexer 282a receives at its two input terminals the first and the third mediate clock signals M1 and M3 generated by the buffer/inverter unit 281, and outputs at its two output terminals two output signals to serve as the first and the third base clock signals B1 and 10 B3, respectively. That is, the first bypass/cross multiplexer 282a outputs a 0-degree/180-degree signal and a 90-degree/270-degree signal respectively as the first base clock signal B1 and as the third base clock signal B3. Similarly, the second bypass/cross multiplexer 282b 15 receives at its the two input terminals the second and the fourth mediate clock signals M2 and M4 generated by the buffer/inverter unit 281, and outputs at its two output terminals two output signals to serve as the second and the fourth base clock signals B2 and B4, respectively. Therefore, the second bypass/cross multiplexer 282b 20 outputs a 45-degree/225-degree degrees signal and a 135-degree/315-degree signal respectively as the second base clock signal B2 and as the fourth base clock signal B4. The table in Figure 7 shows the relation among the 25 control bits CA~CF, the mediate clock signals M1~M4 and the base clock signals B1~B4.

Referring back to Figure 4, the first and the second base 30 clock signals B1 and B2, i.e., the boundaries for defining the phase region of the first clock signal CKI, selected by the base selector 28 are subsequently fed into the first phase interpolator 29a to generate the first clock signal CKI by a weighted average process. Similarly, the third

and the fourth base clock signals B3 and B4, i.e., the
boundaries for defining the phase region of the second clock
signal CKQ selected by the base selector 28 are subsequently
fed into the second phase interpolator 29b to generate the
5 second clock signal CKQ by a weighted average process. The
weighted average process is carried out by the first or the
second phase interpolator 29a or 29b to obtain a weighted
average of two boundary phases, based on a "weight" given
by the position control signal from the digital loop filter
10 26.

More specifically, the first clock signal CKI generated
at the output terminal of the first phase interpolator 29a
has a phase which is a weighted average of the phases of
the first and the second base clock signals B1 and B2. That
15 is, the phase of the first clock signal CKI = (weight) ×
(the phase of the first base clock signal B1) + (1 - weight)
× (the phase of the second base clock signal B2). Similarly,
the second clock signal CKQ generated at the output terminal
of the second phase interpolator 29b has a phase which is
20 a weighted average of the phases of the third and the fourth
base clock signals B3 and B4. That is, the phase of the
second clock signal CKQ = (weight) × (the phase of the third
base clock signal B3) + (1-weight) × (the phase of the fourth
base clock signal B4). As discussed above, the phases of
25 the first and the third base clock signals B1 and B3 are
selected to be separated by 90 degrees and the second and
the fourth base clock signals B2 and B4 are also selected
to be separated by 90 degrees. Therefore, by controlling
weighted average processes in the first and the second phase
30 interpolators 29a and 29b at the same weight, two clock
signals CKI and CKQ having a phase difference of 90 degrees
can be obtained. Figure 8 shows the relation between the

weight represented by the position control signal and the clock signal generated by the weighted average process. The first and the second phase interpolators 29a and 29b can be digitally controlled by the position control signal
5 (weight) to vary the phases of the first and the second clock signals CKI and CKQ, which are thereby adjustable in those 45-degree regions respectively defined by the boundaries B1 and B2 and by the boundaries B3 and B4 selected by the base selector 28. It should be noted that the weight values
10 of 0.75, 0.5 and 0.25 set forth here are for illustrative purpose only.

The phase control of the first and the second clock signals generated by the quadrature phase generator 23 is now explained more specifically with reference to Figure
15 9. Figure 9 shows a phase rotation state machine for the first and the second clock signals CKI and CKQ, in which the clockwise rotation path is represented by solid arrows while the counterclockwise rotation path is represented by dotted arrows. According to the quadrature phase generator
20 23 of the invention, for each of the phase values falling in any regions other than the boundaries, there is only one setting. However, for each of the phase values falling exactly on the boundaries, there are dual settings. For example, to generate a first clock signal CKI with a 0-degree
25 phase, 0-degree and 45-degree signals may be selected respectively for the first and the second base clock signals B1 and B2 as the phase region boundaries, and the weight is set to 1 (state "0A" in Figure 9). Alternatively,
0-degree and 315-degree signals may be selected
30 respectively for the first and the second base clock signals B1 and B2 as the phase region boundaries, and the weight is set to 1 (state "0H" in Figure 9). Accordingly, the

setting of a phase value falling on the boundary depends on the previous steady state of the clock signal. Taking the above 0-degree phase setting as an example, if the previous steady state of the first clock signal CKI falls
5 in region A, then the setting of "0A" is adopted; contrarily, if the previous steady state of the first clock signal CKI falls in region H, then the setting of "0H" is adopted. In some situations, it takes a two-step setting for the phase of a clock signal to rotate out of a boundary. For example,
10 if the present state of the first clock signal CKI is "0A", then only one step is needed for the phase to rotate from the boundary to region A; however, if the present state of the first clock signal CKI is "0H", then two steps are needed for the phase to first pass through a transient state "0A"
15 and subsequently proceed to region A. All rotations across two adjacent regions require passing through a transient state. Figure 10 shows a table for illustrating how the region control signal CA~CF and the position control signal (weight) vary to make the phase rotate, taking the clockwise rotation from region A to region H as an example.
20

With the above structure, the quadrature phase generator according to the invention can be digitally controlled to generate two adjustable quadrature clock signals, the phases of which are allowed to be adjusted thought the whole
25 cycle

While the present invention has been described with reference to the preferred embodiments thereof, it is to be understood that the invention should not be considered as limited thereby. Various modifications and changes
30 could be conceived of by those skilled in the art without departing from the scope of the present invention, which is indicated by the appended claims.